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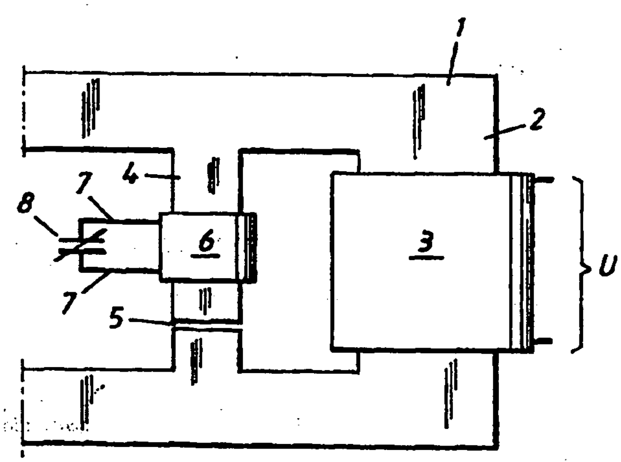

(57) Abstract

An induction controlled voltage regulator, primarily for high voltage regulation, includes a magnetic circuit based upon a metallic core (1) having two or more flux paths or legs (2) with at least one main winding (3) supplying the output voltage (U). Furthermore the voltage regulator includes at least one magnetizable regulation leg (4) with a zone (5) of reduced permeability. The regulation leg is surrounded by a regulation winding (6) connected to a variable capacitor (8). At least one of said windings, or a part thereof, is wound by a high voltage cable comprising at least one current–carrying conductor surrounded by at least a first layer having semiconducting properties, a solid insulating layer and a second layer having semiconducting properties.

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INDUCTION CONTROLLED VOLTAGE REGULATOR

Technical Field

The present invention relates generally to induction controlled voltage regulators and more particularly, to an inductance regulation by an electric transformer or reactor means as defined in the preamble of Claim 1. The invention relates also to a regulator winding used by such an induction controlled voltage regulator as defined in Claim 13 and to a method for voltage control in an electrical line or for reactive power control in plants as defined in Claim 21.

Background of the Invention

Conventional induction controlled voltage regulators for lower voltage ranges are arranged by using inductors with coils rotated or shifted in relation to each other as described in the literature, e.g. by I.L. la Cour and K. Faye-Hansen in the book Die Wechselstromtechnik Bd. 2, "Die Transformatoren", Verlag von Julius Springer, Berlin, Germany, 1936, pages 586 - 598, "Drehtransformator und Schubtransformator". Also this solution involves mechanical movements. Furthermore, such an induction control cannot be made for high voltage at reasonable costs. The insulation construction would be a severe design limitation.

Another technique is known from US-A-4 206 434 where the magnetic flux between different legs of an induction controlled voltage regulator is described to be redistributed by a variable DC magnetization. For this purpose a variable DC-source is needed.

Thus, electric high voltage control is mostly made by electric transformers involving one or more windings wound on one or more legs of the transformer iron core. The windings involve taps making possible of supplying different voltage levels from the transformer. The present power transformers and distribution transformers as those mentioned above and used in voltage trunk lines involve tap-changers for the voltage regulation. They are mechanically complicated and are subject to mechanical wear and electrophysical erosion due to discharges between contacts. Regulation is only possible in steps. Thus, a stepwise voltage regulation and movable contacts are required for connection with the different taps. It may be disadvantageous to include movable means for high voltage control and not to be able to obtain a step-free continuos voltage supply.

Summary of the invention

The drawbacks of prior art voltage regulation are avoided by the induction controlled voltage regulator according to the present invention. The characteristic features are to be found in that the magnetic circuit of th regulator includes at least

on magnetizable regulation leg with a zone of reduced permeability, and by at least one further winding wound around said regulation leg, said further winding being connected to a variable capacitor.

An important condition to make it possible for obtaining such a voltage regulation of high voltages, i.e. 36 kV up to 800 kV, is that at least one of the windings, or a part thereof, in the transformer or the reactor is constructed of a high voltage cable which include at least one conductor, a first layer having semiconducting properties, a solid insulating layer, and a second layer having semiconducting properties. Thus, the transformer/reactor will be of a so called dry type. The use of such a designed high voltage cable makes it possible to "capture" the electric field inside the cable insulation. This means that it is possible to design induction controlled voltage regulators for high voltage applications.

An additional advantage is that said layers are arranged to adhere to one another even when the cable is bent. Hereby, good contact is achieved between the layers during the cable's entire life.

By placing at least one winding loaded with a variable capacity on at least one magnetic flux path (also referred to as a "leg") of the magnetic circuit, this leg having a zone with reduced permeability across the magnetic flux, the reluctance of this leg can be varied by varying the capacitance. This can be used for redistribution of the magnetic flux between different legs of the magnetic circuit. Thus, also the induced voltage across windings surrounding these legs as well as the inductance of the windings is changed. This principle can be used in many different geometrical arrangements depending on the transformer/reactor type, number of phases etc.

The theory behind the negative reluctance of a winding loaded with a capacitance is mainly given by the following idealised equations. A winding loaded with a capacitance forms a negative reluctance $R_C = -n^2 w^2 C$. The number of winding turns n and the regulation of the capacitor capacitance C may be chosen in such a way to correspond to an optional part of the positive reluctance $R_L = l/A\ m_l\ m_0$,

where l is the length of the flux path,
A is the cross section area of the magnetic core,
m_l is the permeability of the flux path, and
m_0 is the permeability of air.

The distribution of the magnetic flux F onto the different legs of the magnetic core, and hence th voltag of th windings wound on th se legs, is variable as a function of the capacitance C.

D pending on the type of capacitance regulation used, the voltage/inductance regulation is continuos or made in small steps, corresponding to discrete capacitances switched into the circuit. Due to relationship between number of turns, capacitance and reluctance, one can choose low turn number combined with low voltage, high current and large capacitance or high turn number combined with high voltage, low current and low capacitance, depending on which realisation of the variable capacitance being most practical. Using the cable concept described in more detail below, the capacitors can be integrated within the transformer/reactor housing, as its windings are potential free.

Brief Description of the Drawings

These and other features and advantages of the present invention will become more apparent from the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawings, in which:

Fig. 1 is a principle view of a part of a transformer core according to the invention having two legs, an air gap and a regulation winding,

Fig. 2 is a principle view of a part of a transformer core according to the invention, one main leg of which being split into two sub-legs, one of which includes the air gap and the regulation winding,

Fig. 3 is a modification of the transformer core part shown in Fig. 2, where both the two sub-legs include air gaps and regulation windings, and

Fig. 4 is a cross-section view of a high voltage cable being used in the regulation windings according to the present invention.

Detailed Description of the Invention

The invention will now be described in detail with reference to some preferred embodiments, the principle of which is shown in the drawing figures enclosed. Like reference numbers used in the different drawings refer to similar or other equipment having a corresponding function. Figs. 1 through 3 show the part of the voltage regulator only being important to the present invention.

Though the drawings show a single phase voltage regulator according to the invention, the man skilled in the art may well understand that the inventive principle also can be used for two or more phases applications.

Fig. 1 shows a part of a transformer or reactor core 1 usually in form of a magnetical iron plate package included in the transformer or reactor magnetic circuit. The magnetic circuit would include two or more main flux paths 2 (or legs as they will be named in the following description). One of the main legs 2 is shown in

Fig. 1 having a main winding 3. In parallel to the main l g 2 th re is shown a magnetizable regulator leg 4 with a zone 5 of reduced permeability. The zone 5 may be an air gap, multiple of gaps, cavities in the core, or solid material inserts having a permeability m_l being lower than the one of the core material or may be obtained by any other suitable means, e.g. as described in US-A-4 047 138.

The regulator leg 4 is surrounded by a further winding 6 (also named regulator winding below), the conductor 7 of which being connected to a variable capacitor 8.

According to the theory behind the negative reluctance of a winding loaded with a capacitance, as mentioned above, the output voltage U of the main winding 3 can be controlled or regulated by changing the capacitance of the capacitor 8.

Another embodiment of such an induction controlled voltage regulator according to the invention is shown in Fig. 2. In this case the main leg 2, carrying the main winding 3 ,is split into two sub-legs 2A and 2B below (downstream) the main winding 3. One of the sub-legs, namely 2A, corresponds to the regulator leg 4 described above with reference to Fig. 1. Thus, the sub-leg 2A comprises a zone 5 with reduced permeability and a regulator winding 6 connected to a variable capacitor 8.

The output voltage U from the main winding 3 is supplied through two sub-windings 3A and 3B connected in series to the main winding 3. The sub-windings 3A and 3B are carried by respective one of the sub-legs 2A and 2B. The sub-windings 3A and 3B are wound opposing each other. Thus, the sub-windings 3A, 3B are wound in such a way that, when the flux is rising in one of the sub-legs and the flux is falling in the other sub-leg, the voltages in the sub-windings 3A, 3B will get the same sign with respect to the main winding 3. Therefore the voltage regulation range is doubled.

Fig. 3 shows a modified embodiment of the one discussed above with respect to Fig. 2. Thus, in the Fig. 3 case both the sub-legs 2A and 2B include zones 5A and 5B with reduced permeability and regulator windings 6A and 6B, each one being connected to a separate variable capacitor 8A and 8B respectively. By having two regulation legs it is possible to increase the regulation range.

To make it possible to obtain a regulation of high voltages, i.e. in the field of about 36 kV through 800 kV, at least one of the windings 3, 3A, 3B, 6, 6A and 6B, or a part of anyone thereof, is wound by using a high voltage cable 61 of a type shown in Fig. 4 as an example.

The cable used in the pr s nt invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for xample, of a solid th rmoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E≤500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Such a high voltage cable 61 may include one or more electrical conductors 631. The cable embodiment shown in Fig. 4 includes an insulation and the conductor 631 is in direct connection with a first layer 632 having semiconducting properties. The first layer 632 is in turn surrounded by a solid insulating layer 633, which then is surrounded by a second layer 634 having semiconducting properties.

In Fig. 4 showing the detail of the invention relating to the cable, the three layers 632, 633, 634 are arranged to adhere to each other even when the cable is bent. The cable shown is flexible, and this property is maintained during the entire life of the cable.

Favourably the layers 632, 633, and 634 are made from the same plastic material or other materials having the same coefficient of expansion. By that the important advantage is obtained in that deficiencies, cracks, etc. are avoided at thermal movement in the winding. The plastic material of the two semiconducting layers 632, 634 has electric conductive material added thereto.

Though the present invention has been described above with reference to a single phase transformer or reactor it is obvious that different applications lies within the field for the man skilled in the art. Thus, e.g. it is possible to apply the present invention to one-phase induction controlled voltage regulators. Also on-load-tap-changer devices, i.e. a one-phase induction controlled voltage regulator integrated in a transformer, are possible to implement. Furthermore, multi-phase induction controlled voltage regulators can be made with individual phase control as well as with common phase control. Thus, the invention also can be applied to such an apparatus having two or more phases. In such a multi-phase transformer each phase can be equipped with a separate regulation leg 4 or legs 2A, 2B. By doing so each phase may have an independent regulation or the regulation windings 6, 6A and/or 6B may be connected for having a joint regulation.

The inventive idea may as well be practised in an autotransformer and in a booster transformer.

CLAIMS

1. An induction controlled voltage regulator, particularly a transformer or a reactor means, comprising a magnetic circuit involving a magnetizable core (1) having two or more main flux paths or legs (2), at least one of which main legs being surrounded by a main winding (3), said regulator being **characterized** by at least one magnetizable regulation leg (4; 2A; 2B) having a zone (5; 5A; 5B) of reduced permeability, and by at least one further winding (6; 6A; 6B) wound around said regulation leg, said further winding being connected to a variable capacitor (8; 8A; 8B), and at least one of the turns of the main winding (3) is comprising a high voltage cable (61) including a conductor (631), a first layer (632) having semiconducting properties, a solid insulating layer (633) provided around said first layer (632) and a second layer (634) having semiconducting properties provided around the insulating layer (633).

2. A regulator according to claim 1, and further **characterized** in that also at least one of the further windings (6; 6A; 6B) is comprising a high voltage cable (61) including a conductor (631), a first layer (632) having semiconducting properties, a solid insulating layer (633) provided around said first layer (632) and a second layer (634) having semiconducting properties provided around the insulating layer (633).

3. A regulator according to claim 1 or claim 2 and further **characterized** in that said zone (5; 5A; 5B) of reduced permeability is of air gap type.

4. A regulator according to claim 3, **characterized** in that each regulation leg (4; 2A; 2B) includes one or more air gaps (5; 5A; 5B).

5. A regulator according to claim 3, **characterized** in that said zone (5; 5A; 5B) of reduced permeability is obtained by cavities made in each said regulation leg (4; 2A; 2B).

6. A regulator according to claim 3, **characterized** in that said zone (5; 5A; 5B) of reduced permeability is obtained by solid inserts of a material with low permeability.

7. A regulator according to any preceding claim, and further **characterized** in that said main leg (2) is split into two sub-legs (2A, 2B), one of the sub-legs forming said regulation leg (2A) having the further winding (6A).

8. A regulator according to any of the claims 1 through 6, and further **characterized** in that said main leg (2) is split into two sub-legs (2A, 2B), each one forming a regulation l g with a further winding (6A, 6B) connected to a variable capacitor (8A, 8B).

9. A regulator according to any of the claims 7 and 8, and further **characterized** in that at least a part of said main winding (3) is formed by two sub-windings (3A, 3B) connected in series to each other, each sub-winding being wound around the sub-leg (2A, 2B) belonging thereto.

10. A regulator according to any preceding claim, and further **characterized** in that said regulator is a multiphase transformer having a regulation leg (4; 2A; 2B) in each phase for independent regulation of each phase.

11. A regulator according to any of the claims 1 through 9, and further **characterized** in that said regulator is a multi- phase transformer having a regulation leg (4; 2A; 2B) in each phase, where the said further windings (6; 6A; 6B) of the regulation legs are connected for having a joint regulation.

12. A regulator according to any of the claims 1 through 9, and further **characterized** in that said regulator is an autotransformer or a booster transformer.

13. A regulator according to any of the preceding claims, and further **characterized** in that said layers (632, 633, 634) are arranged to adhere to one another even when the cable is bent.

14. A regulator winding (6; 6A; 6B) for an induction controlled voltage regulator, particularly a transformer or a reactor means comprising a main winding (3), according to any of the preceding claims, **characterized** in that at least one of said windings (3, 6, 6A, 6B), or a part of anyone thereof, comprises a cable (61) having at least one current-carrying conductor (631), a first layer (632) having semiconducting properties provided around said conductor (631), a solid insulating layer (633) privided around said first layer (632), and a second layer (634) having semiconducting properties provided around said insulating layer (633).

15. A winding according to claim 14, **characterized** in that the potential of said first layer (632) is substantially equal to the potential and the conductor (631).

16. A winding according to claim 14 or 15, **characterized** in that said second layer (634) is arranged to constitute substantially an equipotential surface surrounding said conductor (631).

17. A winding according to claim 16, **characterized** in that said second layer (634) is connected to a specific potential.

18. A winding according to claim 17, **characterized** in that said specific potential is ground potential.

19. A winding according to any of the claims 14 through 18, **characterized** in that at least two of said layers (632 - 634) have substantially equal thermal expansion coefficients.

20. A winding according to any of the claims 14 through 19, further **characterized** in that each of said three layers (632 - 634) is fixed connected to adjacent layer along substantially the whole connecting surface.

21. A winding according to any of the claims 14 through 20, further **characterized** in that said layers (632, 633, 634) are made from the same plastic material, the plastic material of the first and second layers (632, 634) has electric conduction material added.

22. A method for voltage control in an electrical line and/or for reactive power control in plants comprising at least a transformer or a reactor having at least one of its windings, or a part of anyone thereof, being of a high voltage cable type according to any of the preceding claims, where the voltage control is effected by an induction regulation.

23. A method according to claim 22, **characterized** in that said induction regulation is obtained by variation of a regulation voltage supplied to a winding wound around a regulation leg of said transformer or said reactor.

24. A method according to claim 23, **characterized** in that said variation of the regulation voltage is obtained by controlling of a capacitor having a controllable capacitance.

Fig. 1

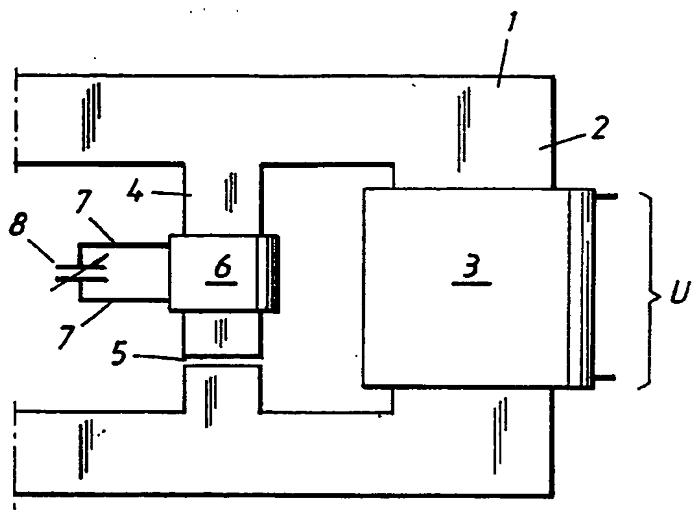

Fig. 2

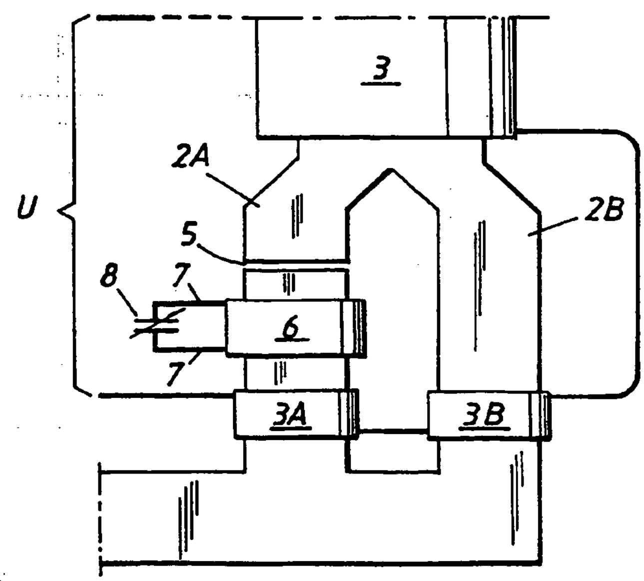

Fig. 3

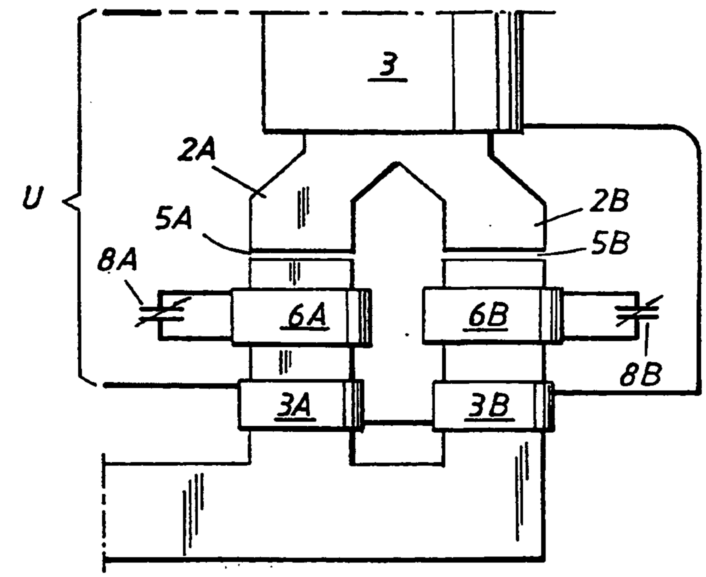

Fig. 4